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(54) Title: POLYMERIC SHEET

(57) Abstract

A polymeric sheet, which is particularly suited for use as a separator in an electrochemical device, is formed, by graft copolymerising acrylic acid, or another vinyl monomer capable of reacting with an acid or a base to form a salt directly or indirectly, with fibres of a non-woven sheet, whose outer surface is provided by a polyolefin, especially polypropylene. The polyolefin is crosslinked as a result of the polymerisation reaction. The polymerisation reaction is preferably initiated by exposure of the sheet to ultraviolet radiation, after impregnation with an appropriate solution of the vinyl monomer.

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POLYMERIC SHEET

The present invention relates to a polymeric sheet and to a method of making a polymeric sheet. The sheet is wettable by aqueous solvents, and is suitable for use in applications where ionic conduction is required, for example as an electrode separator in an electrochemical device.

Separators for use in electrochemical devices such as electrochemical cells are required to permit migration of ionic species for electrochemical reaction on electrode surfaces, and in some cases gases, while presenting a barrier to migration of electrode material between electrodes of a device. Separators can be substantially non-porous for certain applications, when ion migration takes place by an ion exchange mechanism. For certain applications, electrode separators are porous, so that ion migration can take place in liquid electrolyte which impregnates the pores of the separator.

An electrode separator should be capable of withstanding significant levels of physical maltreatment, including being subjected to physical shock such as when a device incorporating the separator is subjected to vibration or is dropped. A separator will sometimes be required to be capable of allowing passage of gas through it. The material of the separator should also be chemically stable towards materials encountered in the device, whether present for electrochemical reaction, or as the product of such a reaction.

In order that the electrochemical characteristics of a device remain substantially constant over a period of time, it is preferred that the ability of ions to migrate through the separator of a device should remain substantially constant. In the case of a porous separator, the material of the separator should be wettable by the device electrolyte, and the wettability of the separator material by the electrolyte should remain substantially constant with time.

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It would appear that certain polyolefin materials have certain physical properties which would make them suitable for use in the manufacture of electrode separators. A difficulty arises, however, in that such materials are not inherently wettable by aqueous electrolytes. Such electrolytes are therefore unable to penetrate the pores of an electrode separator formed from such a material, so that ion migration through the pores in solution is not possible. This problem is sometimes overcome by treating the polyolefin material with a surfactant which allows an aqueous electrolyte to wet the material. However, such surfactant can be removed from the surfaces of the polyolefin material when electrolyte is lost from the device, for example during charging and discharging cycles, and it is not subsequently replaced on the material when the electrolyte is replenished.

This problem has been addressed by modifying the surface properties of polyolefin materials used to form polymeric sheets, for example for use as electrode separators, by graft-copolymerising to those surfaces a monomeric substance which, after co-polymerisation, confers hydrophilic properties and, in some cases ion exchange properties, on the polyolefin substrate. This technique has been found to be practicable when the porous substrate is formed from polyethylene, which has been found to lend itself well to a graft-copolymerisation reaction of this kind. However, it has been found that, when such a reaction is attempted using polyolefin materials other than polyethylene, the rate of the grafting reaction is reduced significantly.

JP-A-82.141862 (Yuasa Battery Company Limited) discloses a separator for a battery, comprising a vinyl monomer which is graft-copolymerised on a non-woven fabric of fibres, the fibres comprising polypropylene resin with a coating of polyethylene resin on their surfaces. Such fibres are formed by co-extrusion. The use of composite fibres of this type allows a separator to be formed which has physical properties which are

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characteristic to some extent of a separator formed from polypropylene. However, the disclosed separator has the significant disadvantage that manufacture of the co-extruded polyethylene-polypropylene fibres is complicated, and relatively expensive.

In one aspect, the invention provides a polymeric sheet which comprises a fabric formed from fibres whose surface is provided by a crosslinked polyolefin with groups bonded to it resulting from a graft-polymerisation reaction between the fibre surface and a vinyl monomer capable of reacting with an acid or a base to form a salt directly or indirectly, the ion exchange capacity of the sheet (IEC meq.g^{-1}) and the gel fraction (G %) of the crosslinked material of the fibres satisfying the condition:

$$\text{IEC} \geq 0.002G + 0.05.$$

It has been found that a polymeric sheet which has the features specified above has a combination of properties which makes it suitable for use as an electrode separator, with the ion exchange capacity which is required for the sheet to be wettable so that it is capable of permitting sufficient ionic conduction through electrolyte contained within it. Moreover, the separator has been found to have a degree of creep resistance, stiffness, abrasion resistance and resistance to cutting through which allow it to withstand maltreatment prior to and during use, for example during the course of assembly of an electrochemical device. The physical properties of the membrane can enhance the ability of the sheet to prevent migration of particles of material, for example in the form of dendrites, through it when it is in use, for example in an electrochemical device as a separator.

The combination of ion exchange capacity and physical properties which are present in the polymeric sheet of the present invention have been found to result from a process of

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manufacture involving irradiation using ultraviolet radiation under conditions which are described in greater detail below. The combination of properties is associated with polymeric sheets which have significant advantages, both in terms of the sheets themselves and the method by which they are made.

The ion exchange capacity of the polymeric sheet is measured in meq.g⁻¹ according to the test routine referred to below. The gel fraction is measured according to ASTM D2765-84. Preferably, the gel fraction is at least about 5%, more preferably at least about 10%, especially at least about 15%.

Preferably, the fabric is a non-woven fabric.

Preferably, the material of the surface of at least some of the fibres, for example at least about 40% by weight, preferably at least about 60%, more preferably at least about 80%, comprises polypropylene. It has been found that a sheet can be made from fibres with a surface which comprises polypropylene having the features referred to above, and that it can be made by a process which is quick and efficient.

Preferably, the material of at least some of the fibres from which the non-woven fabric is formed, for example at least about 40% by weight, preferably at least about 60%, more preferably at least about 80%, is substantially homogeneous throughout the thickness of the fibres. It can be preferred for many applications for the material of substantially all of the fibres to be substantially homogeneous throughout their thickness, so that those fibres are formed only from polypropylene or another suitable material (with appropriate additives where necessary).

It is envisaged that the sheet of the invention may be made from non-woven fabric which is made from fibres comprising more than one material, for example more than one polyolefin, or a single polyolefin but having different physical properties in

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different regions of the fibres. For example, the fabric may be made from at least some fibres formed from two polymers, such as coextruded bicomponent fibres having a polypropylene core and an outer layer of polyethylene, or coextruded fibres with the components positioned side-by-side. Bicomponent fibres can be formed by sintering of particles of a first material onto a core provided by a second material; for example, particles of polyethylene may be sintered onto a core of polypropylene. The fabric might also be made from fibres containing materials having different physical properties as a result of processing or additives. For example, fibres might be used which contain a polymer which has different molecular weights or different molecular structure (arising for example from differences in tacticity) in different regions of the fibres.

Bicomponent fibres may provide substantially the entire content of the non-woven fabric, or a proportion only, for example less than about 60% by weight, perhaps less than about 40%, for example less than about 30%. A small proportion of bicomponent fibres, for example with a polyethylene outer layer or with a lower molecular weight outer layer, can serve to bind the fibres of the fabric together.

When the polymeric sheet is formed from fibres which comprise polypropylene alone, it has the advantage that its physical properties are those of a non-woven fabric formed from polypropylene fibres, which are generally to be preferred compared with those of a fabric formed from polyethylene fibres, and which are quite different from the properties of a membrane formed from a microporous polymer sheet such as might be formed for example from a blend of two materials from which one material is removed. Furthermore, the sheet of the invention can be made more conveniently, and less expensively, than a sheet formed from a non-woven fabric of fibres which comprise two co-extruded materials. A further significant advantage is that the sheet of the invention can be made from

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fibres whose thickness is less than that of fibres formed from more than one material by co-extrusion, because of the absence of constraints which are otherwise placed on an extrusion process when more than one material is involved. As a result, the sheet of the present invention has, in addition to the advantages which arise from the use of polypropylene fibres, the advantages of small pore size in the structure of the sheet, which in turn confers an enhanced ability to filter solid material from a solution, preventing migration of that material through the sheet. A small pore size has the additional advantage that the resulting higher capillary forces can ensure that electrolyte is retained in the pores when the sheet is in use, for example as a separator in an electrochemical device, notwithstanding forces exerted on the sheet which might otherwise cause the electrolyte to be displaced.

Preferably, the thickness of the fibres from which the non-woven fabric is formed is less than about 30 μm , more preferably less than about 10 μm .

Preferably, the size of the pores of the separator, as measured using a Coulter porometer, is less than about 60 μm , more preferably less than about 45 μm , for example less than about 30 μm . Such small pore sizes can be attained using small diameter fibres, such as those referred to above. The use of a separator having a small pore size has the advantage that the ability of the separator to prevent penetration of electrode materials, for example as dendrites, when in use in an electrochemical device is enhanced.

Preferably, the thickness of the sheet, measured using test method DIN 53105 which involves dropping a 2.0 kg weight onto a sample of the sheet of area 2.0 cm^2 at a speed of 2.0 mm.s^{-1} , is greater than about 100 μm , more preferably greater than about 150 μm ; preferably, the thickness is less than about 600 μm , more preferably less than about 450 μm . The method by

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which the sheet is made may include a step of calendering the fabric to reduce its thickness to a value within the range referred to above, the reduction being by at least about 5%, preferably at least about 15%, more preferably at least about 25%, and less than about 60%, preferably less than about 45%, more preferably less than about 40%. The calendering step may take place before or after the material of the fabric is reacted with the graft-polymerisation solution. Calendering the fabric before the graft-polymerisation reaction has been found to give rise to increased rates of the reaction.

The vinyl monomer which is graft-polymerised with the polypropylene of the fibre surface can be capable of reacting with an acid or a base directly to form a salt, or indirectly to form a salt after appropriate work up, perhaps involving for example hydrolysis or sulphonation. Preferred vinyl monomers include ethylenically unsaturated carboxylic acids and esters thereof such as acrylic acid, methacrylic acid, methyl acrylate, and methylmethacrylate. Other vinyl monomers which might be used include acrylamide, vinylpyridine, vinyl-pyrrolidone and styrene-sulphonic acid.

In another aspect, the invention provides an electrochemical device, comprising an anode, a cathode, a quantity of an electrolyte, and an electrode separator of the type discussed above. Preferably, the cathode in the device comprises nickel (II) hydroxide. An example of material which can form the anode in such a device includes cadmium. Alternatively, the anode may be a metal hydride electrode. Other types of electrochemical device in which the separator of the invention finds application include secondary cells such as lead-acid cells.

In a further aspect, the invention provides a method of making a polymeric sheet, which comprises:

- (a) impregnating a non-woven fabric formed from fibres

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whose surface is provided by a polyolefin with a solution of a vinyl monomer capable of reacting with an acid or a base to form a salt directly or indirectly, the solvent being one which does not evaporate to a significant degree in the subsequent step of exposure of the fabric to radiation, and

(b) exposing the impregnated fabric to ultraviolet radiation while exposure of the fabric to oxygen is restricted to cause the monomer and the material of the fibres to co-polymerise.

The method of the invention has the advantages that a polymeric sheet can be made quickly and efficiently on a continuous basis, by virtue of the use of ultraviolet radiation to initiate graft-polymerisation of the monomer and the material of the fibres.

The use of a solvent which does not evaporate to a significant degree in the irradiation step of the method has been found to confer the advantages of providing greater uniformity of properties of the resulting sheet, throughout the thickness of the sheet. Thus there is greater uniformity in the degree of grafting throughout the thickness of the sheet, leading to improved ion exchange properties through the sheet. It is believed that this might arise at least in part because of the transparency of the sheet which is retained as a result of the retention of the solvent in the pores of the fabric. It has also been found that the degree or adverse effects or both of homopolymerisation of the vinyl monomer can be reduced by selection of an appropriate solvent.

Suitable solvents for use in the method of the invention will generally be transparent to ultraviolet radiation, have no atoms which are abstractable when exposed to radiation, have a high specific heat and a high latent heat of vaporisation, and will not react adversely with the material of the fibres of the

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separator. Preferred solvents will have a boiling point which is greater than about 50°C, preferably greater than about 70°C. It is also preferred that the boiling point of the solvent be no higher than a temperature at which the film might be damaged during the course of the irradiation step of the method. For example, the boiling point of the solvent might be selected to be less than the temperature at which the material of the fibres melts or softens. Particularly preferred solvents have a latent heat of vaporisation which is greater than about 1000 J.g⁻¹, preferably greater than about 1500 J.g⁻¹, more preferably greater than about 2000 J.g⁻¹, and/or a specific heat capacity which is greater than about 2.0 J.g⁻¹.K⁻¹, preferably greater than about 3.0 J.g⁻¹.K⁻¹, more preferably greater than about 4.0 J.g⁻¹.K⁻¹. A value of specific heat capacity, or of latent heat of vaporisation, within these ranges has the advantage that the solvent in the reaction has an enhanced ability to dissipate heat without evaporating to a significant degree, giving rise to the advantages referred to above. A particularly significant further advantage is that the formation of product from the homopolymerisation reaction of the vinyl monomer is restricted, and any such product which is formed is retained in solution rather than being deposited in the pores within the sheet. This allows the product to be removed easily from the sheet by washing. The control over the formation of the homopolymerisation product can be achieved without use of inhibiting agents, which can cause contamination problems when the sheet is in use in certain applications.

Water is a particularly preferred solvent.

The ultraviolet radiation initiated polymerisation reaction can be completed surprisingly quickly, for example by exposing the impregnated fabric to radiation for as little as 15 seconds, even as little as 5 or 10 seconds, and it has been found that the fabric after reaction contains a significant amount of grafted monomer, which can be sufficient for the fabric to be rendered wettable by aqueous solutions such as might be found

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in certain electrochemical devices. This is to be contrasted with techniques in which graft-copolymerisation reactions are initiated using, for example, electron bombardment, either of impregnated fabric or of fabric prior to exposure to monomer solution, where reaction times of many minutes, even as long as 50 minutes, can be required in order to obtain a significant degree of grafting, and even after reaction times of this order, the degree of grafting reaction can be too low for many applications. Such prior techniques do not therefore lend themselves to continuous processing in the manner of the present invention.

Techniques by which exposure of the impregnated fabric to oxygen can be restricted include, for example, carrying out the ultraviolet irradiation step in an inert atmosphere, for example in an atmosphere of argon or nitrogen, or sealing the impregnated fabric between sheets of material which are impervious to oxygen, but are transparent to ultraviolet radiation of appropriate wavelength for initiating the co-polymerisation reaction.

Preferably, the impregnation solution includes an initiator for the polymerisation reaction. Preferably, the initiator initiates the reaction by abstracting an atomic species from one of the reacting materials, for example by abstracting a hydrogen atom from the polypropylene of the fabric fibres to create a polymeric radical. Following such abstraction, the polymeric radical, in contact with the monomer in solution, can initiate the formation of a grafted branch. When an atom is abstracted from the polypropylene of the fabric fibres, the activated polypropylene molecule can react either with another polypropylene molecule so that the polypropylene of the fabric becomes cross-linked, or with the vinyl monomer in a co-polymerisation reaction. An example of a suitable initiator is benzophenone. The mole ratio of the vinyl monomer to the initiator is preferably at least about 50, more preferably at least about 100, especially at least about 175; the ratio is

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preferably less than about 1500, more preferably less than about 1000, especially less than about 500, more especially less than about 350; for example the ratio may be about 200.

The impregnation solution may include a component by which homopolymerisation of the vinyl monomer is inhibited. Examples of suitable inhibitors include iron (II) and copper (II) salts which are soluble in the reaction medium, a preferred material for aqueous media being iron (II) sulphate. It has been found, however, that the need for an inhibitor can be avoided by selection of an appropriate solvent for the graft-polymerisation reaction which can restrict the speed and degree of the homopolymerisation reaction, for example as a result of its ability to act as a heat sink. This can be an advantage when it is desired to minimise the amount of contaminants in the sheet.

The impregnation solution may include additional components to optimise reaction conditions such as surfactants to ensure that the solution fully impregnates the non-woven fabric, an appropriate mixture of solvents to ensure homogeneity of the solution, and so on.

The use of ultraviolet radiation in the method of the invention allows non-woven fabrics suitable for use as electrode separators to be made economically and on a continuous basis. It has been found that sufficient energy can be supplied to an impregnated fabric for the irradiation process to be run continuously, and that the heat which is generated in such a process can be controlled by use of appropriate solvents as heat sink components.

Measurement of ion exchange capacity

A sample of membrane about 0.5 g is converted into the acid (H^+) form by immersion in 1.0 M hydrochloric acid at 60 °C for 2 hours. The sample is washed in distilled water until the

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washing water shows a pH in the range of about 6 to 7. The sample is then dried to constant weight (W_1) at 100°C.

The dried sample is placed in a 100 ml polyethylene bottle to which is added accurately 10 ml of approximately 0.1 M potassium hydroxide. Additional distilled water can be added to immerse the sample fully. A further 10 ml of potassium hydroxide is added to a second polyethylene bottle, together with the same amount of distilled water as that added to the bottle containing the sample. Both bottles are stored at 60°C for at least two hours.

After being allowed to cool, the contents of each bottle are transferred to glass conical flasks, and the amount of potassium hydroxide in each is determined by titration with standardised 0.1 M hydrochloric acid, using a phenolphthalein indicator.

The ion exchange capacity, measured in milliequivalents per gram, of the membrane in the dry acid (H^+) form is calculated according to the equation:

$$IEC = \frac{t_2 - t_1}{10W_1}$$

where t_1 is the titration value of HCl from bottle with the sample, t_2 is the titration value of HCl from bottle without the sample, and W_1 is the weight of the dried membrane in acid (H^+) form.

Examples of the manufacture of an electrode separator from a non-woven polypropylene fabric is set out below.

EXAMPLE 1

Manufacture of Separator

A non-woven polypropylene fabric made from thermally bonded

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endless single component polypropylene fibre, fibre diameter in the range 5 to 10 μm , was selected having a nominal thickness of 230 μm , and a weight of about 40 g.m $^{-2}$.

A piece of the fabric measuring 12 cm by 12 cm was impregnated by immersion in a solution formulated as follows (percentages by weight):

Acrylic acid	20.0%
Benzophenone	0.5%
Iron (II) Sulphate	0.1%
Lutensol ON 70 Surfactant	0.5%
Methoxyethanol	12.5%
Water	66.4%

The impregnated fabric was placed between two layers of an optically clear polyester film (thickness 75 μm). A laminate was passed through a pair of nip rollers to expel any air and excess solution from between the component layers.

The laminate was placed into a polyethylene bag to provide physical support, and the bag was sealed. The sealed bag was then passed at a speed of 0.3 m.min $^{-1}$ (so that the material of the sheet was exposed to radiation for about 20 seconds) between two medium pressure mercury vapour lamps, positioned parallel to one another. Each lamp had a power output of 120 W.cm $^{-1}$, and produced a parallel beam having a width of 10 cm. The distance between each lamp and the impregnated fabric was 8.5 cm.

Following irradiation, the fabric was removed from the bag and from between the layers of polyester film. It was then washed in water, and then in methanol, to remove unreacted components, and any homopolymerised acrylic acid which may have been formed. The fabric was then further treated in 5% by weight potassium hydroxide at 60°C for two days, to remove any final traces of homopolymerised acrylic acid. The fabric was then

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finally washed with water and dried for 30 minutes at 105°C.

Properties of separator material

The properties of the grafted separator material are set out below, and compared with the corresponding properties of the polypropylene fabric starting material:

	<u>Ungrafted</u>		<u>Grafted</u>	
Ion exchange capacity (meq.g ⁻¹)	0		1.0	
Gel content (%) (ASTM D2765-84)	0		60	
Machine direction tensile strength (ASTM D 882) (N.m ⁻¹)	2400±17		2860±175	
Machine direction elongation (%) (ASTM D 882)	72±10		63.5±9	
Electrolyte wicking rate (time) (30% w/w KOH) (DIN 53924-78) (mm)	60s 0	600s 0	60s 30	600s 70
Electrolyte absorbtion (%) (AD 447301 US Air Force Manual)	Non-wetting		184	
Electrical Resistance (ohm.cm ²) (AD 447301 US Air Force Manual)	Non-wetting		0.042	

The properties referred to above demonstrate that acrylic acid has been grafted to the polypropylene fabric material, so that the fabric has become wettable, and therefore suitable for use in electrochemical devices which include aqueous electrolyte.

In a further test, involving storing the separator in 40% by weight potassium hydroxide at 71°C for 21 days, it has been

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found that the properties referred to above have changed only to an insignificant degree, showing that the wettability imparted to the non-woven polypropylene fabric by the grafting reaction is permanent.

EXAMPLE 2

Manufacture of Separator

A non-woven polypropylene fabric made from thermally bonded endless single component polypropylene fibre, fibre diameter in the range 5 to 10 μm , was selected having a nominal thickness of 330 μm , and a weight of about 60 g.m $^{-2}$. The fabric was calendered to reduce its thickness to about 200 μm .

A strip of the fabric on a roll was impregnated with a solution formulated as follows (percentages by weight) by passing the fabric around rollers located in a chamber with an atmosphere of nitrogen, so that the fabric passed through the solution:

Acrylic acid	30.0%
Benzophenone	0.25%
Lutensol ON 70 Surfactant	0.5%
Water	69.25%

The mole ratio of acrylic acid to benzophenone was about 150.

The impregnated fabric, still in a nitrogen atmosphere, was passed at a speed of 1.0 m.min $^{-1}$ (so that the material of the sheet was exposed to radiation for about 6 seconds) between two medium pressure mercury vapour lamps, positioned parallel to one another, one on each side of the chamber, the walls of the chamber at that point being provided by quartz windows. Each lamp had a power output of 120 W.cm $^{-1}$, and produced a parallel beam having a width of 10 cm.

The fabric was then washed in de-ionised water to remove

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unreacted components, and dried in an air oven for 2 minutes at 95°C.

Properties of separator material

The properties of the grafted separator material are set out below, and compared with the corresponding properties of the polypropylene fabric starting material:

	<u>Ungrafted</u>		<u>Grafted</u>	
Ion exchange capacity (meq.g ⁻¹)	0		0.48	
Gel content (%) (ASTM D2765-84)	0		33	
Machine direction tensile strength (ASTM D 882) (N.m ⁻¹)	3140±50		3650±175	
Machine direction elongation (%) (ASTM D 882)	93±6		78±9	
Electrolyte wicking rate (time) (30% w/w KOH) (DIN 53924-78) (mm)	60s 0	600s 0	60s 30	600s 70
Electrolyte absorbtion (%) (AD 447301 US Air Force Manual)	Non-wetting		350	
Electrical Resistance (ohm.cm ²) (AD 447301 US Air Force Manual)	Non-wetting		0.070	

EXAMPLE 3

A non-woven fabric formed from bicomponent polypropylene/polyethylene fibres (thickness 145 µm, basis weight 60 g.m⁻²) was impregnated with a solution having the following composition, using the apparatus described in Example 2 above:

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Acrylic acid	30.0%
Benzophenone	0.5%
Lutensol ON 70 Surfactant	0.5%
Water	69.0%

The properties of the grafted separator material are set out below, and compared with the corresponding properties of the polypropylene fabric starting material:

	<u>Ungrafted</u>	<u>Grafted</u>
Ion exchange capacity (meq.g ⁻¹)	0	0.567
Gel content (%) (ASTM D2765-84)	0	45.7
Machine direction tensile strength (ASTM D 882) (N.m ⁻¹)	3512±100	4706±75
Machine direction elongation (%) (ASTM D 882)	27.6±3.9	26.9±1
Electrolyte wicking rate (time) (30% w/w KOH) (DIN 53924-78) (mm)	60s 600s 0 0	60s 600s 25 60
Electrolyte absorbtion (%) (AD 447301 US Air Force Manual)	Non-wetting	190
Electrical Resistance (ohm.cm ²) (AD 447301 US Air Force Manual)	Non-wetting	0.058

EXAMPLE 4

An AA size commercially available nickel-metal hydride (Misch metal electrode) cell was dismantled and its separator was replaced with one made by the method described in Example 2 above. Electrical connections were made to the electrodes, and

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the components of the altered cell were placed in a container having dimensions approximately equal to those of the original cell. An appropriate amount of 30% potassium hydroxide electrolyte was added to the cell components, and the cell was sealed with an epoxy resin adhesive.

The cell was charged and discharged repeatedly at a C/20 rate (that is over a cycle which involved charging for 20 hours and discharging for 20 hours), and was found to be capable of delivering 700 mAh to a 1.0V cut-off on discharge.

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CLAIMS:

1. A polymeric sheet which comprises a fabric formed from fibres whose surface is provided by a crosslinked polyolefin with groups bonded to it resulting from a graft-polymerisation reaction between the fibre surface and a vinyl monomer capable of reacting with an acid or a base to form a salt directly or indirectly, the ion exchange capacity of the sheet (IEC meq.g^{-1}) and the gel fraction (G %) of the cross-linked material of the fibres satisfying the condition:

$$\text{IEC} \geq 0.002G + 0.05.$$

2. A sheet as claimed in claim 1, in which the material of the fibre surface comprises polypropylene.

3. A sheet as claimed in claim 1 or claim 2, in which the material of the fibres is substantially homogeneous throughout the thickness of at least some of the fibres.

4. A sheet as claimed in any one of claims 1 to 3, in which the vinyl monomer comprises an ethylenically unsaturated carboxylic acid or an ester thereof.

5. A sheet as claimed in any one of claims 1 to 4, in which the thickness of the fibres is less than $30 \mu\text{m}$, preferably less than $10 \mu\text{m}$.

6. An electrochemical device, comprising an anode, a cathode, a quantity of an electrolyte, and an electrode separator provided by a sheet as claimed in any one of claims 1 to 5.

7. A device as claimed in claim 6, in which the cathode comprises nickel (II) hydroxide and in which the anode comprises cadmium or a metal hydride electrode.

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8. A device as claimed in claim 6, which is a lead-acid cell.
9. A method of making a polymeric sheet, which comprises:
 - (a) impregnating a non-woven fabric formed from fibres whose surface is provided by a polyolefin with a solution of a vinyl monomer capable of reacting with an acid or a base to form a salt directly or indirectly, the solvent being one which does not evaporate to a significant degree in the subsequent step of exposure of the fabric to radiation, and
 - (b) exposing the impregnated fabric to ultraviolet radiation while exposure of the fabric to oxygen is restricted to cause the monomer and the material of the fibres to co-polymerise.
10. A method as claimed in claim 9, in which the solvent comprises water.
11. A method as claimed in claim 9 or claim 10, in which the vinyl monomer comprises an ethylenically unsaturated carboxylic acid or an ester thereof.
12. A method as claimed in any one of claims 9 to 11, in which the impregnation solution includes a component by which homopolymerisation of the monomer is inhibited.

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 92/01245

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)⁶

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.C1. 5 H01M2/16; D06M14/28; B01J47/12

II. FIELDS SEARCHED

Minimum Documentation Searched⁷

Classification System	Classification Symbols		
Int.C1. 5	H01M ;	D06M ;	B01J

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched⁸III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
E	DATABASE WPIL Derwent Publications Ltd., London, GB; AN 92-280621 & JP,A,4 192 256 (JAPAN STORAGE BATTERY CO) 7 October 1992 see abstract ----	1-4,6,7
X	DATABASE WPIL Derwent Publications Ltd., London, GB; AN 88-288745 & JP,A,63 210 143 (NITTO ELECTRIC IND KK) 31 August 1988 see abstract & Derwent Publications Ltd., London, GB; AN 88-288745 & JP,A,63 210 143 (NITTO ELECTRIC IND KK) 31 August 1988 see abstract ----	1,3,4,6
A		9-12 -/-

¹⁰Special categories of cited documents:

- ¹¹A" document defining the general state of the art which is not considered to be of particular relevance
- ¹²"E" earlier document but published on or after the international filing date
- ¹³"L" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- ¹⁴"O" document referring to an oral disclosure, use, exhibition or other means
- ¹⁵"P" document published prior to the international filing date but later than the priority date claimed

- ¹⁶"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- ¹⁷"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- ¹⁸"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- ¹⁹"A" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

30 OCTOBER 1992

Date of Mailing of this International Search Report

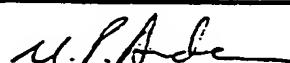
24. 11. 92

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

ANDREWS M.P.



III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	EP,A,0 221 645 (YARDNEY CORP.) 13 May 1987 see page 1, paragraph 2; claims 1,2,5 ---	1,3-7
X	US,A,5 024 767 (NAMI KUBO) 18 June 1991 see column 4; example 1 see column 2, line 64 - column 3, line 7 see column 3, line 20 - line 32 ---	1,3-5
X	DATABASE WPIL Derwent Publications Ltd., London, GB; AN 88-195876 & JP,A,63 135 432 (JAPAN ATOMIC ENERGY RESEARCH) 7 June 1988 see abstract ----	1,3,4
A	US,A,3 341 366 (RUSSELL BATES HODGDON) 12 September 1967 see column 4, line 23 - line 27; claim 27 -----	1,6

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. GB 9201245
SA 61888**

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 30/10/92

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EP-A-0221645	13-05-87	JP-A-	62076252	08-04-87
US-A-5024767	18-06-91	None		
US-A-3341366		BE-A- CH-A- DE-A,B,C FR-A- GB-A- NL-A- US-A-	668486 463462 1570681 1452148 1096879 6510859 3442825	16-12-65 12-03-70 21-02-66 06-05-69